037-B327 IN M31: LUMINOUS GLOBULAR CLUSTER OR CORE OF A FORMER DWARF SPHEROIDAL COMPANION TO M31?[1]

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ABSTRACT

037-B327 is of interest because it is both the most luminous and the most highly reddened cluster known in M31. Deep observations with the Advanced Camera for Surveys on the *Hubble Space Telescope* provide photometric data in the F606W band, and also show that this cluster is crossed by a dust lane. We determined the structural parameters of 037-B327 by fitting the observed surface brightness distribution to a King model with $r_c = 0.72''(= 2.69$ pc$)$, and $r_t = 5.87''(= 21.93$ pc$)$, and a concentration index $c = \log(r_t/r_c) = 0.91$. The surface brightness profile appears to be essentially flat within $0.25''$ of the center and shows no signs of core collapse. Although the dust lane affects the photometry, the King model fits the surface brightness profile well except for the regions badly affected by the dust lane. We also calculate the half-light radius $r_h = 1.11''(= 4.15$ pc$)$. Combined with previous photometry, we find that this object falls in the same region of the M_V versus $\log R_h$ diagram as do ω Centauri, M54 and NGC 2419 in the Milky Way and the massive cluster G1 in M31. All four of these objects have been claimed to be the stripped cores of former dwarf galaxies. This suggests that 037-B327 may also be the stripped core of a former dwarf companion to M31.

Subject headings: galaxies: evolution – galaxies: individual (M31) – globular cluster: individual (037-B327)

1. INTRODUCTION

It has been speculated that some of the most luminous known globular clusters might be the remnants of tidally stripped dwarf galaxies nuclei (Zinnecker et al. 1988; Freeman 1993; Bassino et al. 1994). The study of globular clusters in M31 was initiated by Hubble (1932), who discovered 140 GCs with $m_{pg} \leq 18$ mag. The continued importance of the study of GCs in this galaxy has been reviewed by Barmby et al. (2000). M31 globular cluster B327 (B for 'Baade') or Bo037 (Bo for 'Bologna', see Battistini 1987), which, in the nomenclature introduced by Huchra et al. (1991) will subsequently be referred to as 037-B327. The extremely red color of this object was first noted by Kron & Mayall (1960).

The brightest globular clusters in M31 are more luminous than the giant Galactic cluster ω Centauri. Among these are 037-B327 (van den Bergh 1968) and G1 (see details from Barmby et al. 2002a). The latter has been considered as the possible remnant core of a former dwarf galaxy which lost most of its envelope through tidal interactions with M31 (Meylan & Heggie 1997; Meylan et al. 2001). Subsequently Mackey & van den Bergh (2005) strengthened the Meylan & Heggie (1997) and Meylan et al. (2001) conclusion.

In this paper, we have determined the structural parameters of 037-B327 using its deep image obtained with

the Advanced Camera for Survey (ACS) on the *Hubble Space Telescope* (*HST*). Combined with the previous photometry, we find that this cluster lies in the same region of the $\log R_h$ versus M_V diagram as do ω Centauri, M54 and NGC 2419 in the Milky Way and G1 in M31. This suggests that 037-B327 may also be the remnant core of a now defunct dwarf companion to the Andromeda galaxy.

2. OBSERVATIONS AND DATA REDUCTION

We searched the *HST* archive and found 037-B327 to have been observed with the ACS-Wide Field Channel (WFC) in the F606W and the F814W bands. We mainly used the image in F606W, which was observed on 2004 August 2 with 2370.0 seconds of exposure time. We deconvolve the image using the IRAF task Lucy (Lucy 1974). The image of 037-B327 observed in the F606 and its deconvolved counterpart are shown in Figure 1. The central structure is clearly more complex in the deconvolved image. The *HST* ACS-WFC resolution is $0.05''$ per pixel. We used the IRAF task Ellipse to fit the image with a series of elliptical annuli from the center to the outskirts, with the length of the semi-major axis increasing by 10% in each step. Figure 2 shows the ellipticity and position angle, plotted as a function of the semi-major axis. The ellipticity varies significantly with position along the semi-major axis a. The mean ellipticity is $\epsilon \simeq 0.23$. The position angle P.A. is not significantly variable for semi-major axis values a larger than $0.5''$. It is of interest to note that the high ellipticity of 037-B327, which is the most luminous cluster in M31, confirms the empirical rule (van den Bergh 1996) that the brightest globular cluster in a galaxy is also usually one of the most flattened ones. The ellipticities and position angles shown in Fig. 2 (particularly near $r = 0.5''$) are quite

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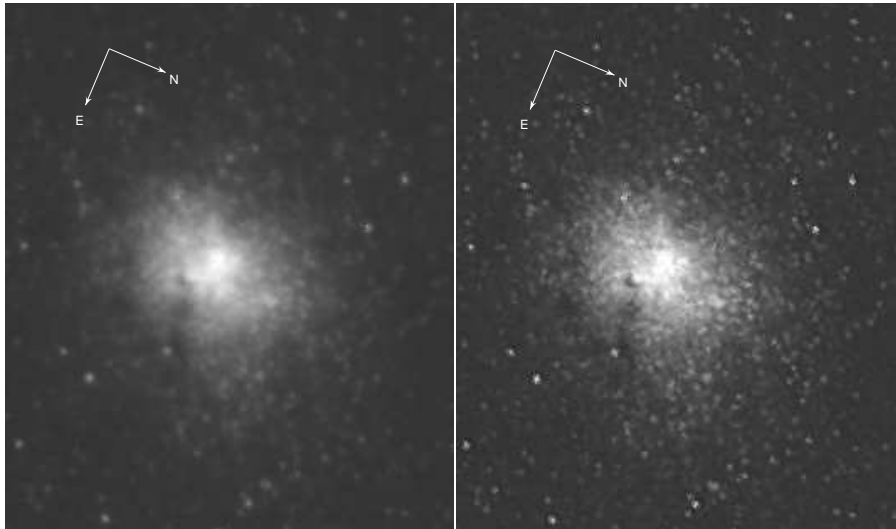
FIG. 1.— The image of GC 037-B327 observed in the F606 (left) and its deconvolved counterpart (right). The central structure is clearly more complex in the deconvolved image. The image size is $7.8'' \times 8.8''$.
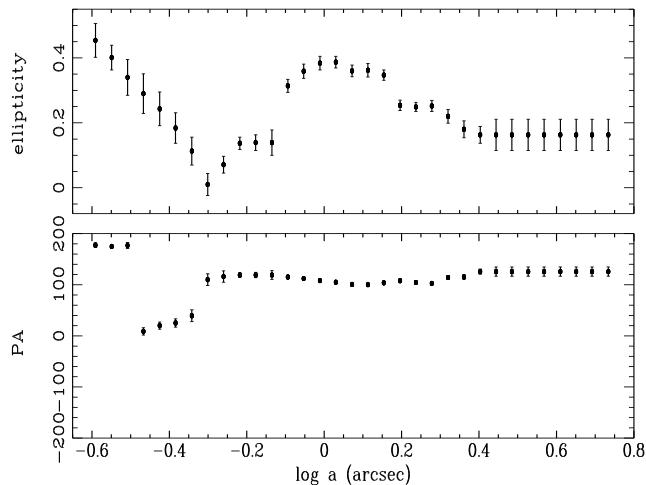
strongly affected by the dust lane.

FIG. 2.— Ellipticity and position angle as a function of the semimajor axis, which are quite strongly affected by the dust lane, particularly near $r = 0.5''$ ($\log a = -0.3$).

We fitted King models (King 1962) to the surface brightness profiles. As usual, we parameterize the model with the core radius r_c, the concentration index $c = \log(r_t/r_c)$ (r_t is the tidal radius.), and $\mu(0)$, the central surface brightness. The derived parameters are: the core radius $r_c = 0.72''$, the tidal radius $r_t = 5.87''$, implying the concentration index $c = \log(r_t/r_c) = 0.91$. The surface brightness profile appears to be essentially flat within $0.25''$ of the center and shows no signs of core collapse. The central surface brightness is 17.21 mag arcsec^{-2}. Figure 3 plots the surface brightness profile and a fitted King model. As we noted, this cluster contains a clear dust lane (see from the images in Figure 1, especially from the deconvolved image). So, some data points are affected by this dust lane, which is evident in

Figure 3. Except for some photometric data affected badly by the dust lane, the King model fits the surface brightness profile well. We also calculate the half-light radius (the radius that contains half of the light in projection) to be $r_h = 1.11''$. With an adopted a distance to M31 of 770 kpc (Meylan et al. 2001), the core radius, the half-light radius and the tidal radius are 2.69 pc, 4.15 pc and 21.93 pc, respectively.

3. ABSOLUTE MAGNITUDE FOR 037-B327

037-B327 is remarkable for being the most luminous and the most highly reddened (van den Bergh 1968) cluster in M31. Vetešnik (1962a) determined magnitudes of 257 M31 GC candidates in the UBV photometric system including 037-B327. Using his photometric catalog, Vetešnik (1962b) studied the intrinsic colors of M31 GCs, and found that 037-B327 was the most highly reddened with $E(B - V) = 1.28$ in his sample of M31 GC candidates. Using low-resolution spectroscopy, Crampton et al. (1985) also found this cluster to be the most highly reddened GC candidate in M31, with $E(B - V) = 1.48$. With a large database of multicolor photometry, Barmby et al. (2000) determined the reddening value for each individual M31 GC including 037-B327 using the correlations between optical and infrared colors and metallicity by defining various "reddening-free" parameters. Again, Barmby et al. (2002a) derived the reddening value for this cluster, using the spectroscopic metallicity to predict the intrinsic colors. The dust lane showed in Figure 3, might be responsible for the bulk of the reddening. In this paper, we adopted $E(B - V) = 1.32 \pm 0.05$ for 037-B327 derived by Barmby et al. (2002a) by the weighted combination of values from their two methods (see details from Barmby et al. 2002a), and $m_V = 16.82$ presented by Barmby et al. (2000). Assuming $R_V = 3.1$ and a distance to M31 of 770 kpc (Meylan et al. 2001), the absolute magnitude of 037-B327 is $M_V = -11.71$, which makes it the most luminous globular cluster in M31.
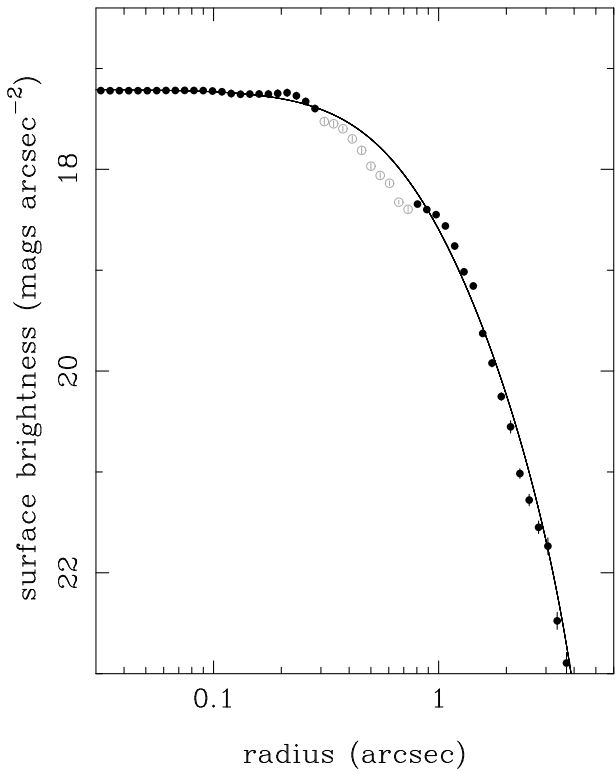
FIG. 3.— Surface brightness profile of 037-B327, the continuous line represents the King model fitted to the observed profile. When fitting this profile we did not use the data plotted as open circles since they were badly affected by the dust patches.
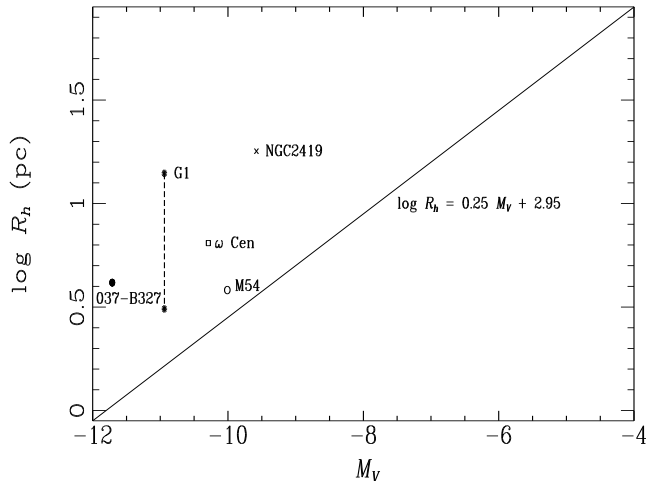

FIG. 4.— Relation between M_V and R_h for 037-B327. The figure shows that 037-B327 lies above and to the brightward of Equation (1) in the M_V versus $\log R_h$ plot. The data for ω Centauri, M54, NGC 2419, and G1 were taken from Mackey & van den Bergh (2005). G1 is marked by two linked stars - representing the two discrepant measurements of R_h for this cluster. The upper point is the measurement of Meylan et al. (2001), while the lower point is that of Barmby et al. (2002b)

4. LUMINOUS GLOBULAR CLUSTER OR CORE OF A FORMER DWARF SPHEROIDAL COMPANION TO M31

As a globular cluster evolves its core contracts and its envelope expands. However, it has been shown by Spitzer & Thuan (1972), Henon (1973),

Lightman & Shapiro (1978), and Murphy et al. (1990) that the half-light radius of an evolving cluster changes little over periods as long as 10 relaxation times. The half-light radius of a cluster therefore can be used to trace the initial size of a cluster, and hence the physical conditions in its host galaxy at early epochs. In previous papers (van den Bergh & Mackey 2004; Mackey & van den Bergh 2005), it was showed that three Galactic globular clusters and one M31 globular cluster lie above and to the brightward of the line

$$\log R_h = 0.25 M_V + 2.95, \qquad (1)$$

where R_h and M_V are the half-light radius and the absolute magnitude of a globular cluster. Figure 11 of Mackey & van den Bergh (2005) showed that the overwhelming majority of normal globular clusters lie below and to the faintward of the line defined by Equation (1). The clusters that do fall above the relation defined by Equation (1) are mostly objects suspected of being the cores of now defunct dwarf galaxies.

Figure 4 shows a plot of $\log R_h$ versus M_V. On this plot 037-B327 is seen to lie above and to the brightward of the line defined by Equation (1) as do ω Centauri, M54 and NGC 2419 in the Milky Way and the massive cluster G1 in M31. All four of these objects have been suggested to be the stripped cores of former dwarf galaxies (for details see Mackey & van den Bergh 2005). This result suggests that the most luminous cluster 037-B327 in M31 may also be the stripped core of a now defunct dwarf companion to M31.

5. SUMMARY

In this paper, we determine the structural parameters of 037-B327 that were derived from an F606W image that was obtained with the Advanced Camera for Surveys on the *Hubble Space Telescope*, by fitting between the surface brightness distribution and the King model. Combined with the previous photometry, we find that this object falls in the same region of the M_V versus R_h diagram as do ω Centauri, M54 and NGC 2419 in the Milky Way and the massive cluster G1 in M31 on the size ($\log R_h$) versus luminosity (M_V) diagram. All four of these objects have been suggested to be the stripped cores of former dwarf galaxies. So, we argue that 037-B327 may also be the core of a former dwarf spheroidal companion to M31. We also compared the images of the F606W and F814W, and did not find any difference in the colors of the brightest incipiently resolved stars, where this term is used in the sense that the image is not clearly resolved into individual stars, but has a mottled or granular appearance, which was employed by Baade (1963).

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